Classic Bearing Damage Modes

Ryan D. Evans, Ph.D.

Manager – Bearing Fundamentals & Tribology

The Timken Company

Wind Turbine Tribology Seminar

NREL-Argonne-DoE

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Goals

- **Introduce to classic bearing damage modes**
  - Recognize types of bearing damage
  - Offer possible causes for bearing damage
  - Suggestions for the prevention of damage

- **"White Etch Areas" damage mode**
  - Terminology
  - Background on microstructural alterations
  - Recent transmission electron microscopy (TEM) investigations

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How is bearing life defined?

- A rolling mill roll neck bearing may have extended service life even with signs of damage if properly repaired.
- High speed dental hand piece bearing life determined by bit speed at a given driving pneumatic pressure.
- Wheel end bearing for mining truck may be limited by peeling and spalling damage.
- Medical equipment bearing life limited by noise and vibration characteristics.
- Wind turbine main shaft bearing limited by occurrence of spalls.

Divide damage modes into two categories:
Material Fatigue & Wear

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Bearing Damage Modes:
Material Fatigue

- L_{10} fatigue life – the number of hours (or cycles) that 90% of a group of (apparently identical) bearings will meet or exceed, under a given set of conditions, before specified fatigue damage occurs.

- Life models predict statistical likelihood that material defects in cyclic stressed volume will create spalls.
  - Factor-based analysis (catalog with adjustment factors)
  - Stress-based analysis

- Adjustment factors on predicted life account for:
  - Reliability
  - Material
  - Environmental conditions (lubrication, misalignment, debris…)

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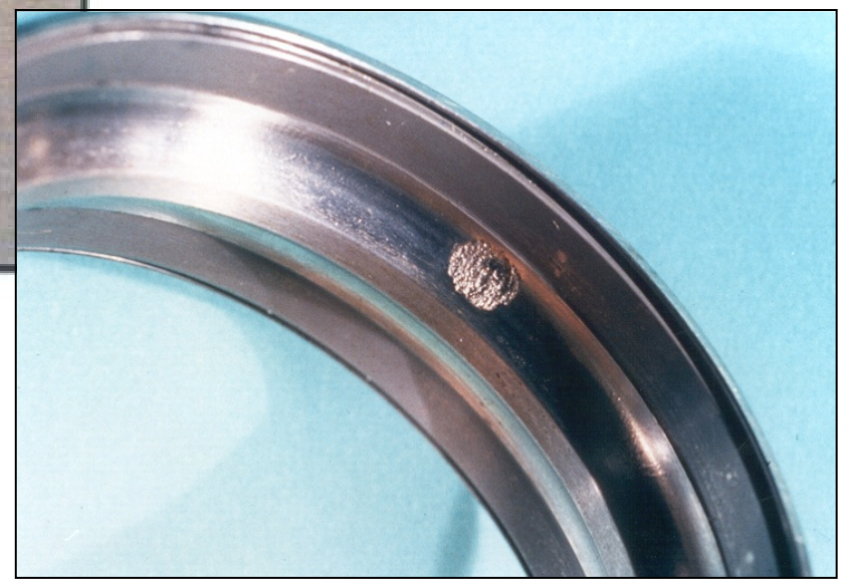
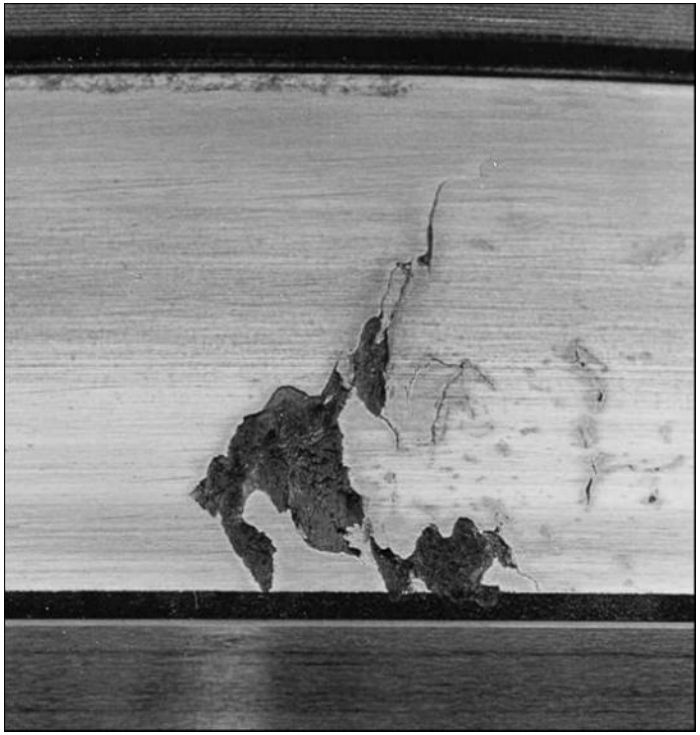
Material Fatigue:
Spalling

Material Fatigue:
Inclusion Origin Spalling

INCLUSION



Material Fatigue:
Point Surface Origin (PSO) Spalling



Spalling from debris or raised metal exceeding lubricant film thickness on a tapered roller bearing

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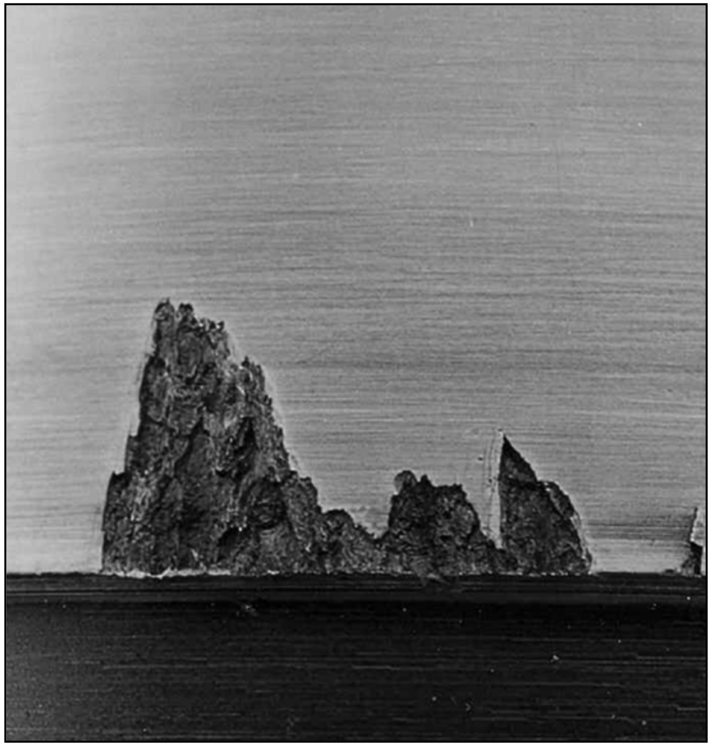
Material Fatigue:
Geometric Stress Conc. (GSC) Spalling



Spalling from misalignment, deflections or heavy loading on a tapered roller bearing

Bearing Damage Modes:
Wear or Other Damage

- Potential causes of wear or other damage are numerous:
  - Faulty mounting
  - Improper adjustment
  - Lack of lubrication
  - Contamination
  - Improper handling, storage, or transport
  - Improper maintenance
  - Exceeding machine limits
  - Environmental factors (temperature, atmosphere, etc.)
- Divide damage causes into (3) general categories:
  - Contamination
  - Inadequate Lubrication
  - Misuse

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Contamination:
Abrasive Wear

Tapered roller bearing abrasive wear

Spherical roller bearing fine particle contamination

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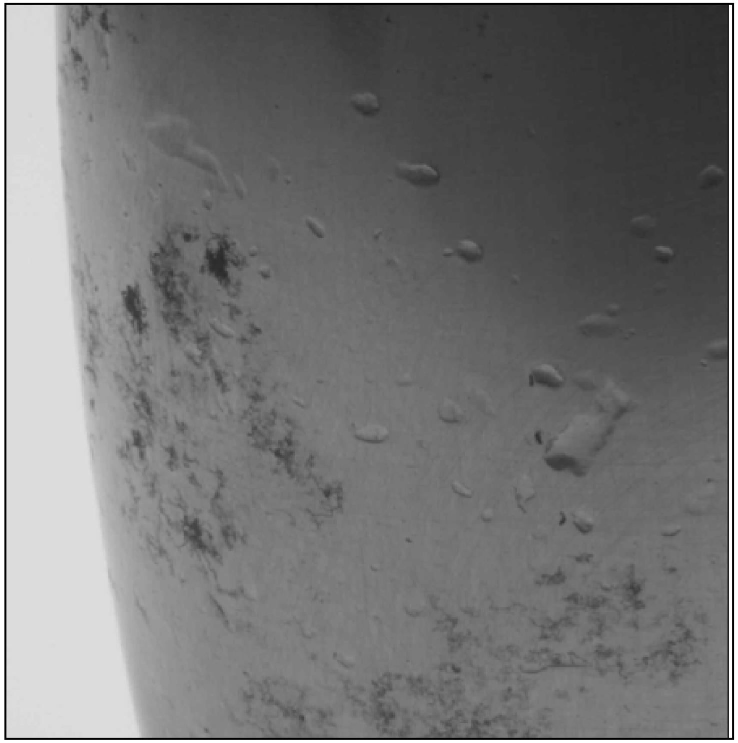
Contamination:
Bruising

Cylindrical roller bearing outer ring bruising



Contamination bruising from hard particles in spherical roller bearing

Contamination:

Denting

Debris denting

Ball

Tapered roller

Spherical roller

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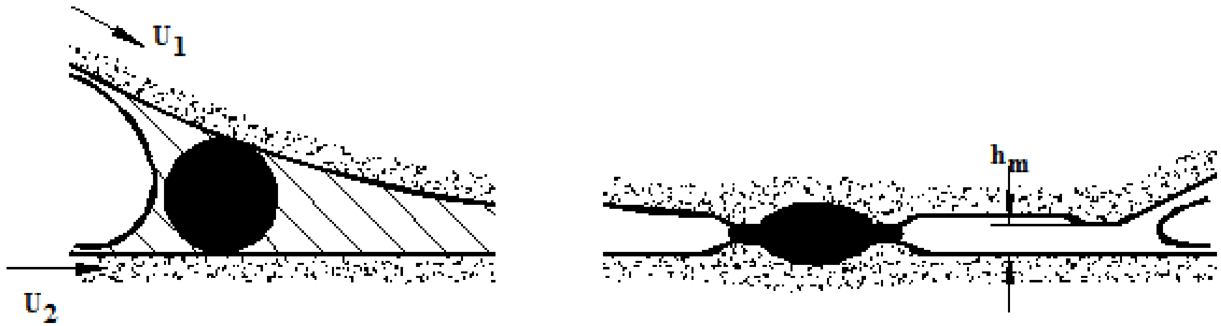
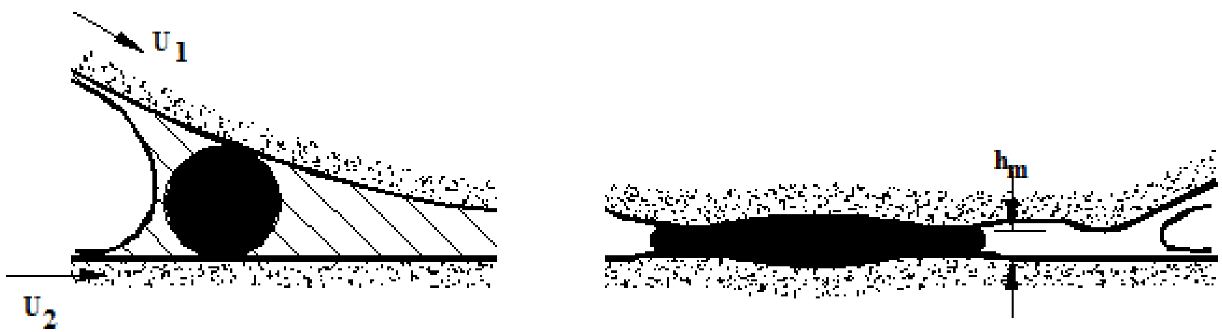
Contamination:
Soft vs. Hard Ductile Particles



Hard Ductile Particle



Soft Ductile Particle

Contamination:
Prevention of Particulate Damage

- Regular inspection of seals
- Ensure clean lubricant supply
- Use proper bearing removal, cleaning and replacement procedures
- Don’t remove bearing from package until ready for mounting
- Ensure clean shop and tools
- Protect from dirt
- Regular maintenance or replacement of filtration elements. Do not bypass the filter.

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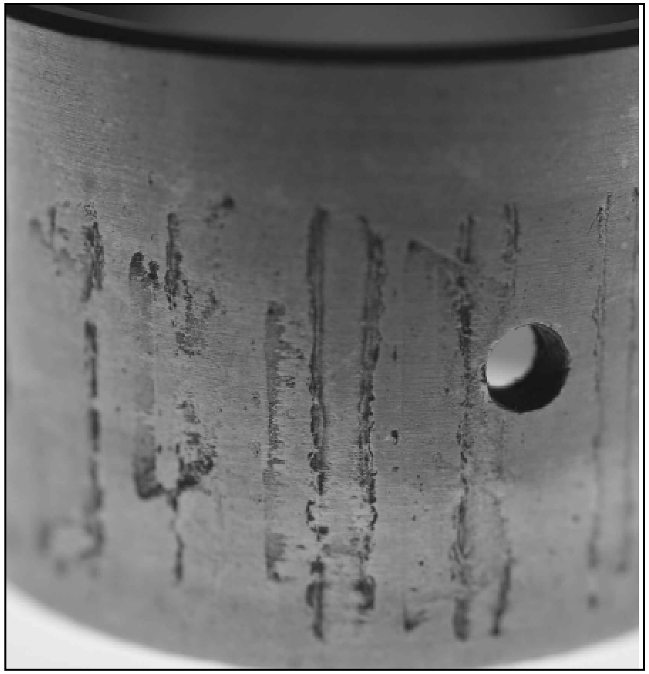
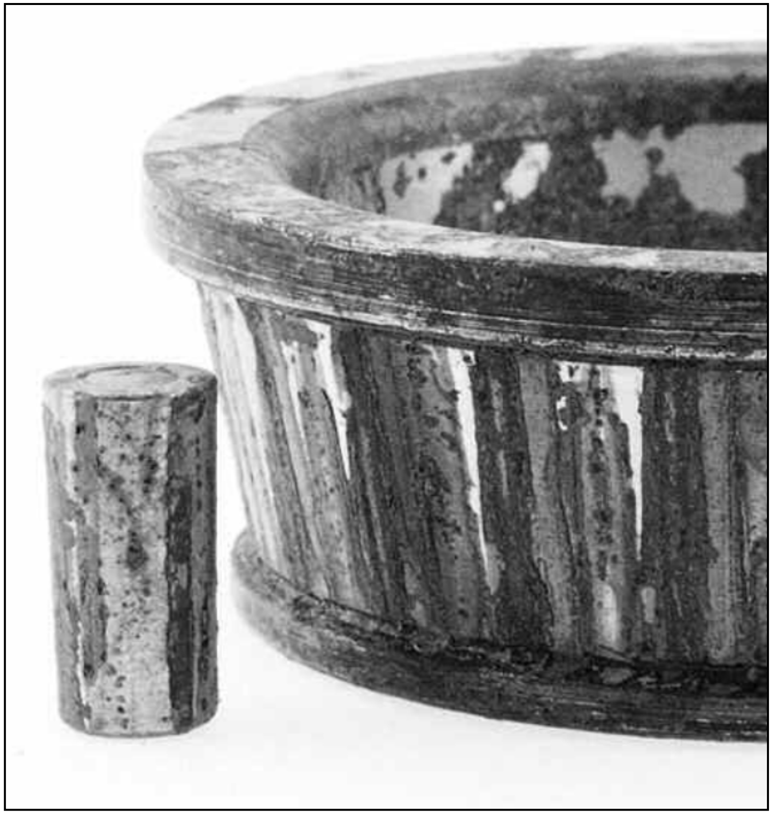
Contamination:
Etching / Corrosion



Etching and corrosion on cylindrical roller bearing inner ring



Advanced corrosion and pitting on the cone race and rollers

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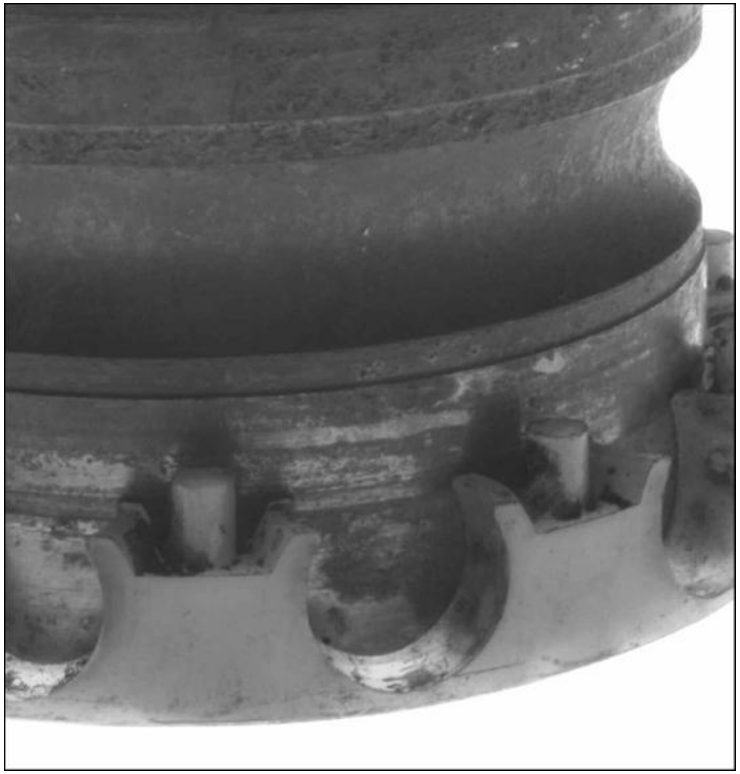
Contamination:
Etching / Corrosion



Heavy water damage on a ball bearing inner ring and cage

A tapered roller bearing cup with corrosion on the race

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Contamination:
Etching / Corrosion Prevention

- Inspect and replace worn seals to avoid etching due to exposure to moisture
- Monitor moisture level in lubricant
- Ensure that bearings are stored in a dry area
    - Before storage, bearings should receive a coating of oil or other rust preventative
    - Wrap bearings in protective paper or covering
- After washing / cleaning, bearings should be thoroughly dried

Contamination:
Fretting Corrosion

Inadequate Lubrication

- Any condition that allows metal-to-metal contact in a bearing can be regarded as “inadequate lubrication”
- Sources / Causes:
  - Lubricant starvation
  - Insufficient lubricant to sustain a film
  - Wrong kind of lubricant for the speed and load
  - Wrong grade of lubricant
  - Wrong type of lubricant system, such as the use of an oil level and splash system when operating conditions require a circulating system

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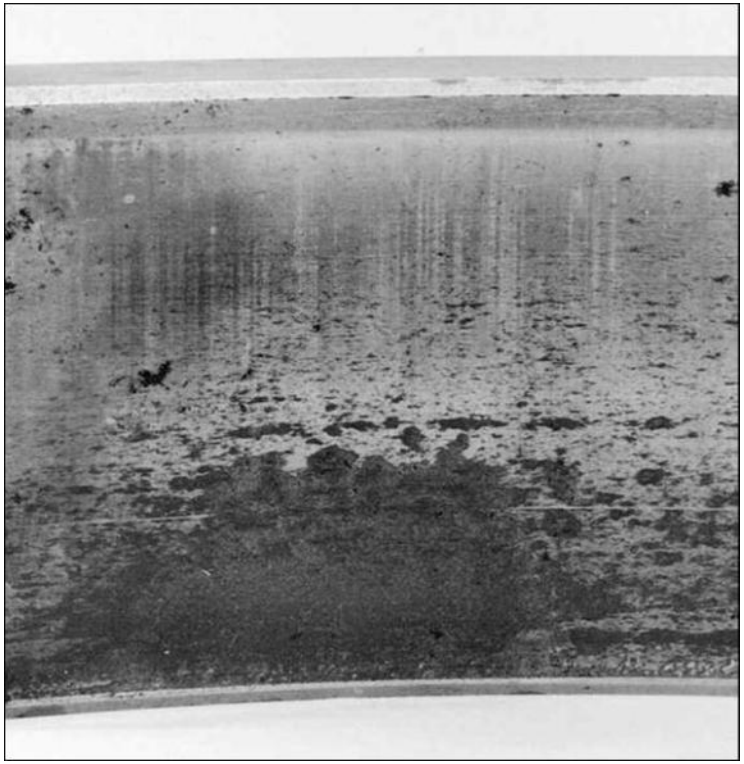
Inadequate Lubrication:
Peeling



Microspalling (peeling) due to thin film from high load/low RPM or high temperatures

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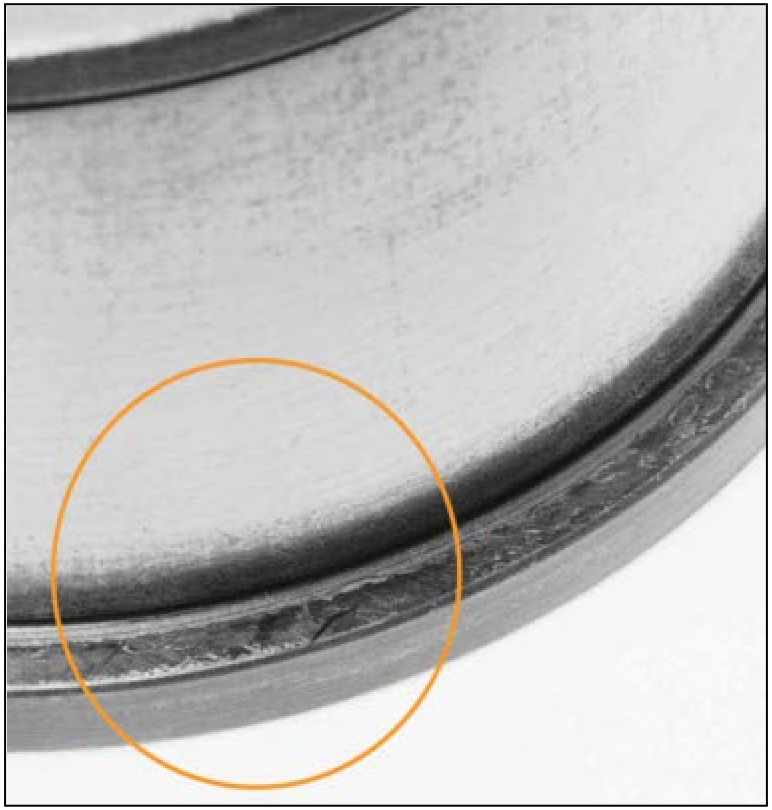
Inadequate Lubrication:
Rib – Roller End Scoring

Heat damage on tapered rollers from metal-to-metal contact



Scoring of tapered roller ends and rib face

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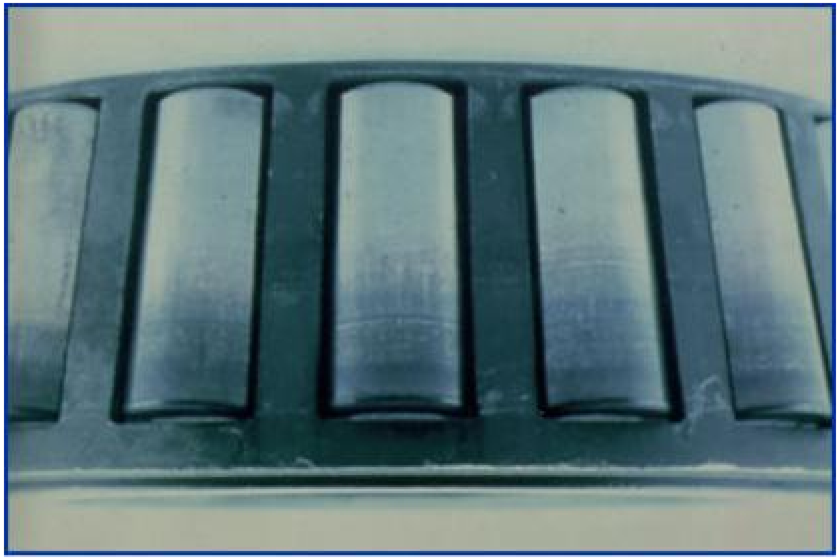
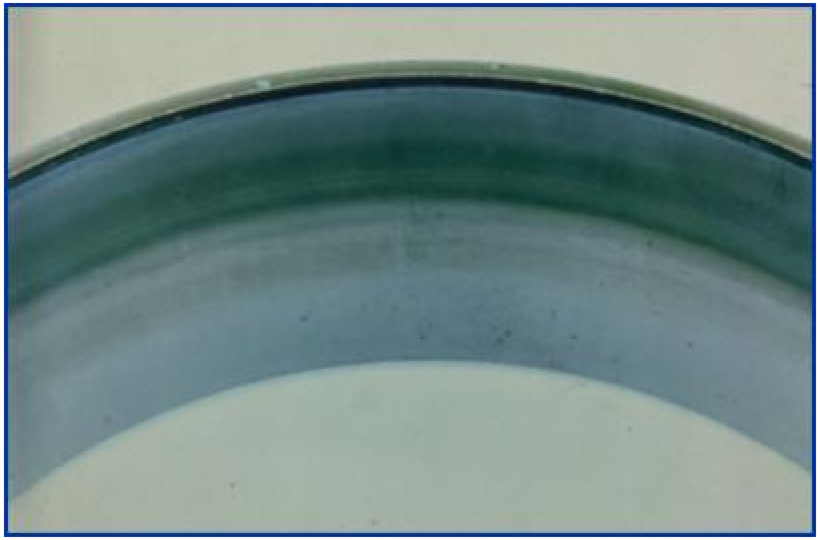
Inadequate Lubrication:
Heat Discoloration





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Inadequate Lubrication:
Smearing

- **Thrust SRB Roller with Smearing Damage**

Smear bands

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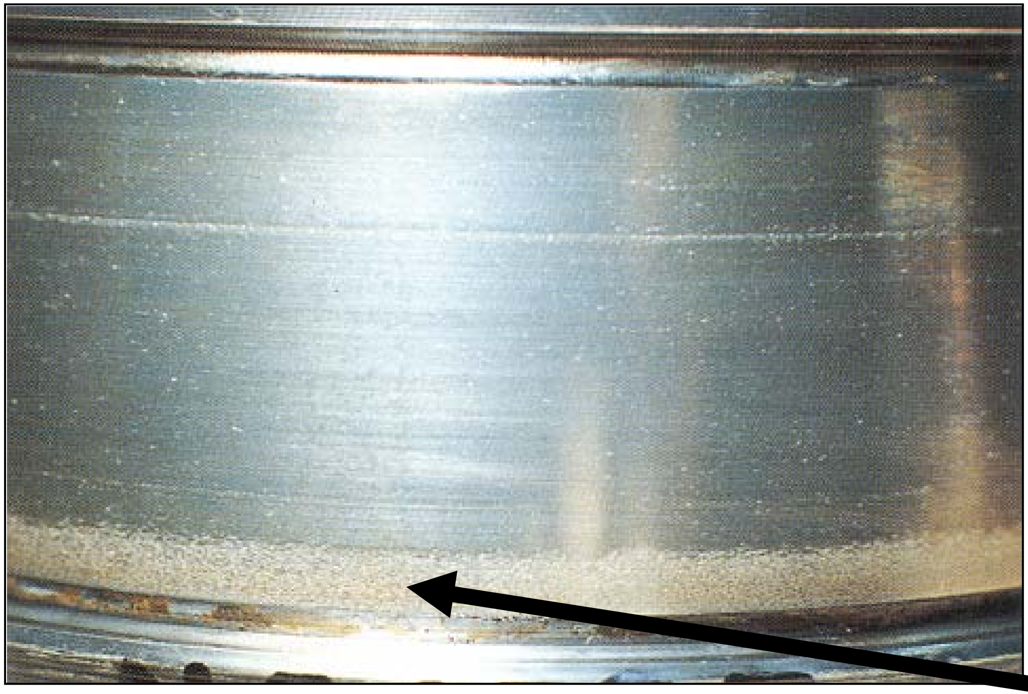
Inadequate Lubrication:

Smearing



- **Smeared TRB Cone Raceway**

Smearing

Goal – Produce smearing in full-scale CRB, and evaluate effectiveness of surface treatment options to mitigate it.

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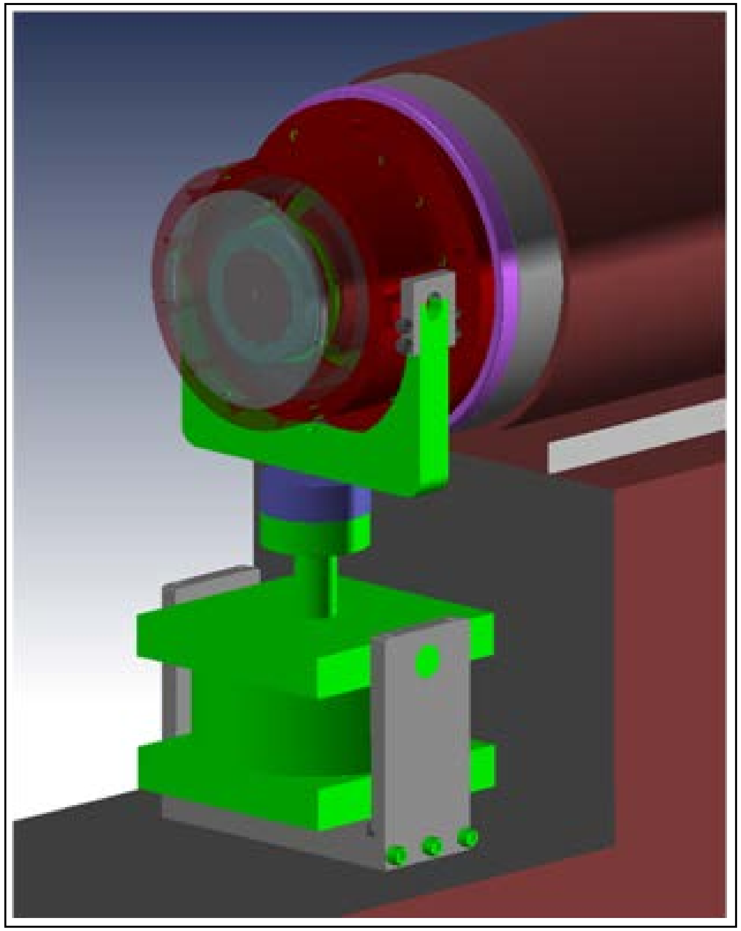
Full-Scale CRB Smearing Test Program:

Test Equipment and Materials



Timken 4-S Test Rig

Rig Characteristic	Range or Description
Speed (rpm)	0 to 3600
Radial Load (kN)	0 to 44.5
Thrust Load (kN)	0 to 22.3
Temperature Sensing	Thermocouples for oil and test bearings
Spindle Torque	Inline torque meter
Cage Speed	Proximity sensor/tachometer
Vibration	Accelerometer

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Full-Scale CRB Smearing Test Program:
Test Equipment and Materials

- **T-6411-A cylindrical roller bearing**
  - **NU-type.**
  - **OD = 290 mm, Bore = 160 mm, Width = 98.425 mm**
- **(4) test treatments, (3) bearings tested per treatment**

Treatment ID	Treatment Description
Ground	Standard Ground Rings and Rollers
Honed / ES20	Honed Raceways, ES20 Roller Texturing
Honed / ES20 / Black Oxide	Honed Raceways, ES20 Roller Texturing, Black Oxide Treatment on both Rings and Rollers
Wear-Resistant	Honed Raceways, ES322 Texture and Coating on Rollers

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Full-Scale CRB Smearing Test Program:
Test Protocol

- **It was not easy to achieve smearing!**
- **Attempted conditions include:**
  - Steady state load and speed conditions for short and long test durations
  - Monotonic load level step-down at constant speed
  - Oscillating load level between a constant “high” level and successively lower step levels at constant speed
  - Oscillating load level between a constant “low” level and successively higher step levels at constant speed
  - Stepping the load level above and below a constant “medium” level at constant speed
  - Fixing various constant load levels and dropping the speed to a low level and then rapidly accelerating to a higher level
  - Various oil type, temperature, and starvation conditions
  - etc…

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Full-Scale CRB Smearing Test Program:
Test Protocol

- **A constant speed test with a two-stage radial load profile worked.**
  - **1st load stage: square wave, alternating load direction between 12 & 6 o'clock.**
  - **2nd load stage: nominal "zero" load condition (small load to offset shaft weight).**

Test Parameter	Value
Load (kN) (as a function of time in min)	$P(t)=\begin{cases}17.8(-1)^{\lfloor 4t \rfloor}, \ if \ 0 \le t \le 40 \\ 0.7, \ if \ 40 < t \le 100\end{cases}$
Speed (rpm)	1800
Oil Flow Rate (mL/min)	47.3
Oil Inlet Temp	Not Controlled – Lab Temp
Oil Type	SAE 20, Polyalphaolefin Synthetic with no EP/AW Additives
Total Test Duration (min)	100

*** 17.8 kN is ~1.5% C1 rating for bearing**

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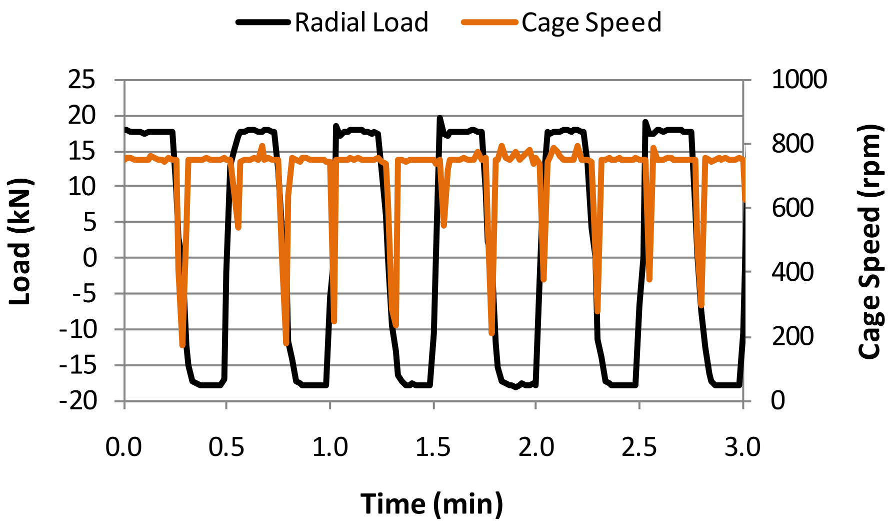
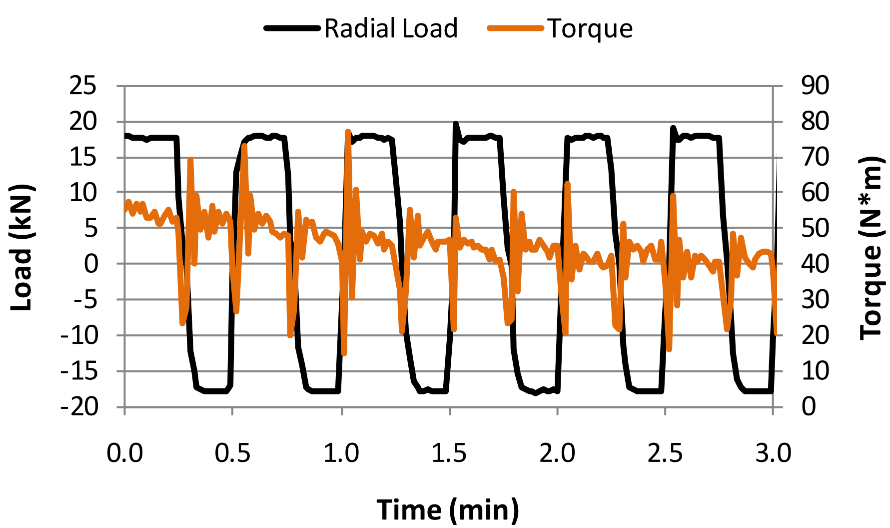
Full-Scale CRB Smearing Test Program:
Test Results





- **Smearing achieved by creating high roller-raceway sliding conditions via load direction reversal.**
- **First (3) mins of a representative test shown at left:**
  - **Significant drop in cage speed during load disengagement and subsequent cage/roller acceleration on reengagement.**
  - **Accompanying torque instability during load direction change.**

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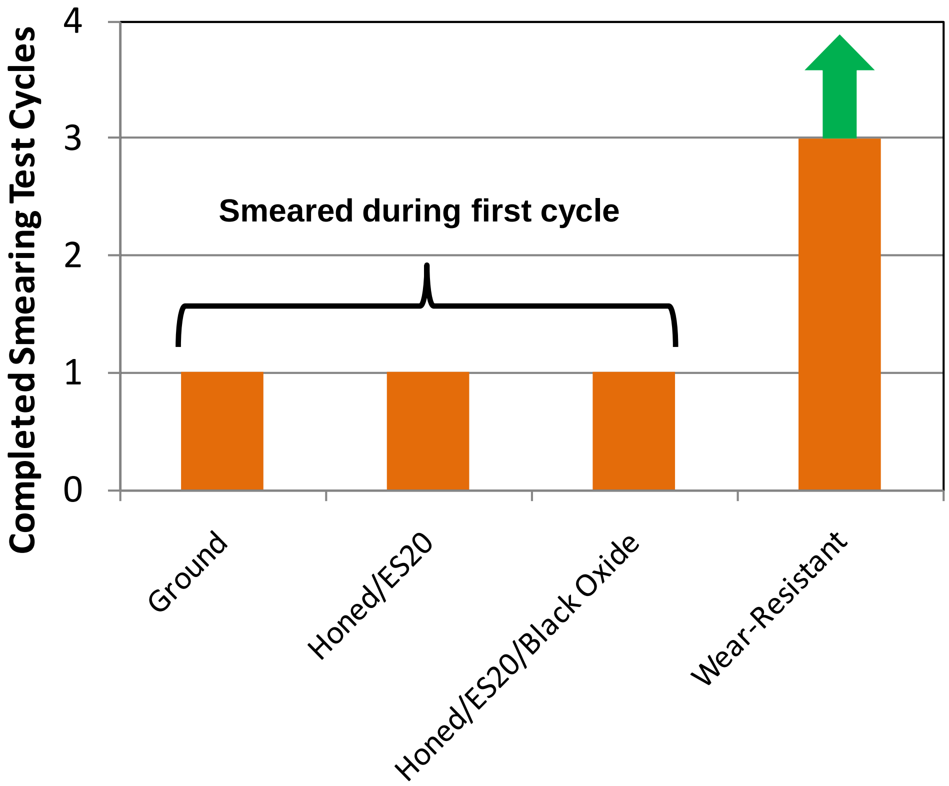
Full-Scale CRB Smearing Test Program:
Test Results



Each bar represents (3) replicate tests from which no variation in result from test to test was observed. That is, all WRB tests were suspended after 3 test cycles with no smearing. All standard tests smeared after 1 test cycle, etc.

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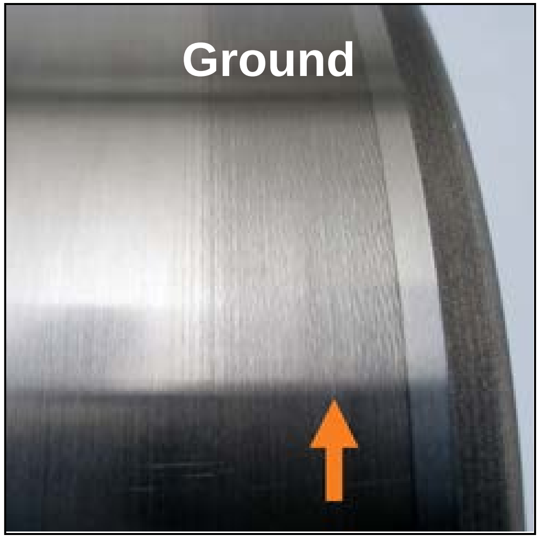
Full-Scale CRB Smearing Test Program:
Post-Test Bearing Analysis



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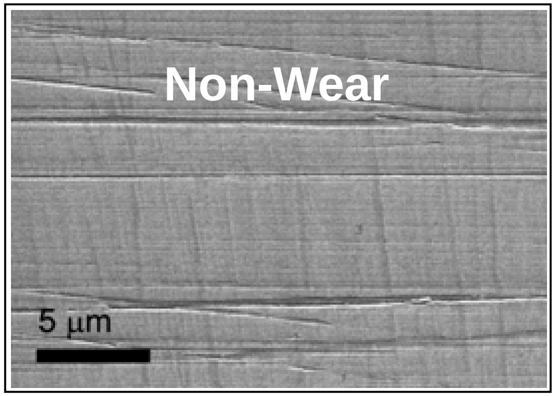
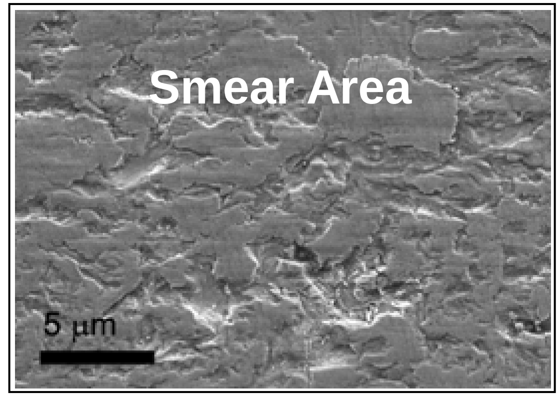
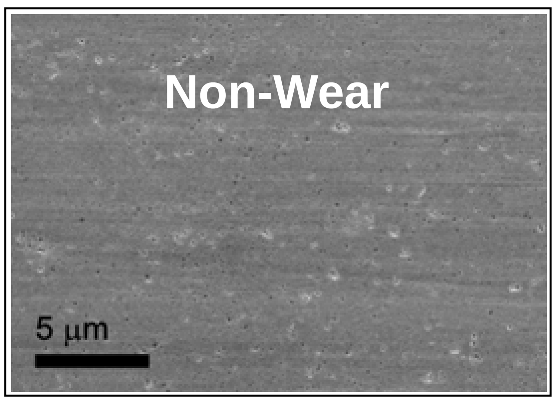
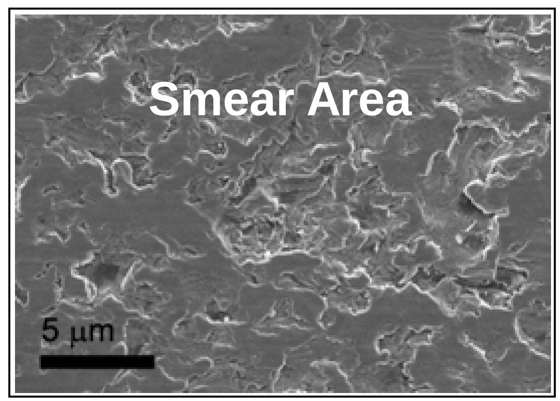
Full-Scale CRB Smearing Test Program:
Post-Test Bearing Analysis





Honed/ES20

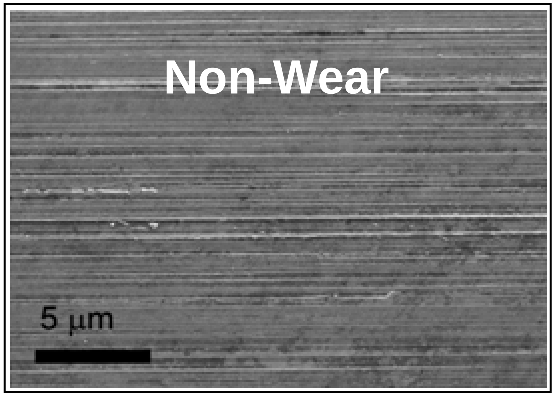


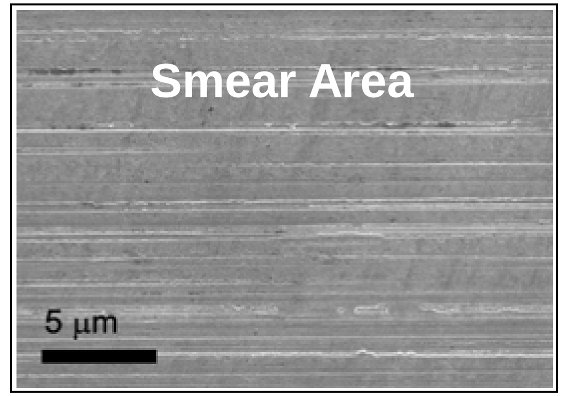


Honed/ES20/Black Oxide

Adhesive Wear Damage

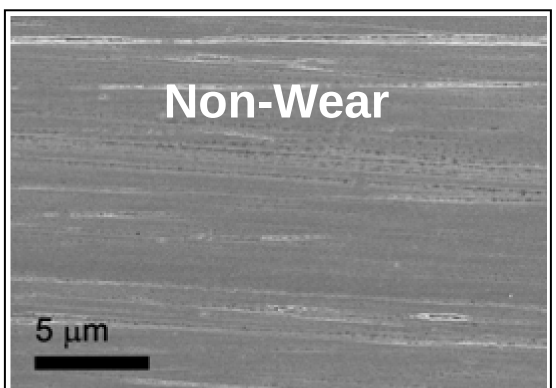
Full-Scale CRB Smearing Test Program:
Post-Test Bearing Analysis





Mild Plastic Deformation

Ground



No smear area

Wear-Resistant

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Full-Scale CRB Smearing Test Program:
Post-Test Bearing Analysis

- **Smearing damage was achieved in full-scale CRB using a two-part test with a period of repetitive load direction reversals (load ~1.5% of the C1 dynamic load rating) followed by steady operation at a nominal zero-load condition.**
- **Wear-Resistant bearings featuring special roller coatings were the only treatment that prevented smearing in these tests.**
- **Black oxide treatment did not provide additional smearing protection over the Honed/ES20 case that had similar raceway and roller body roughness in these tests.**
- **Surface finish and roughness specifications must be carefully considered in applications that are susceptible to smearing.**

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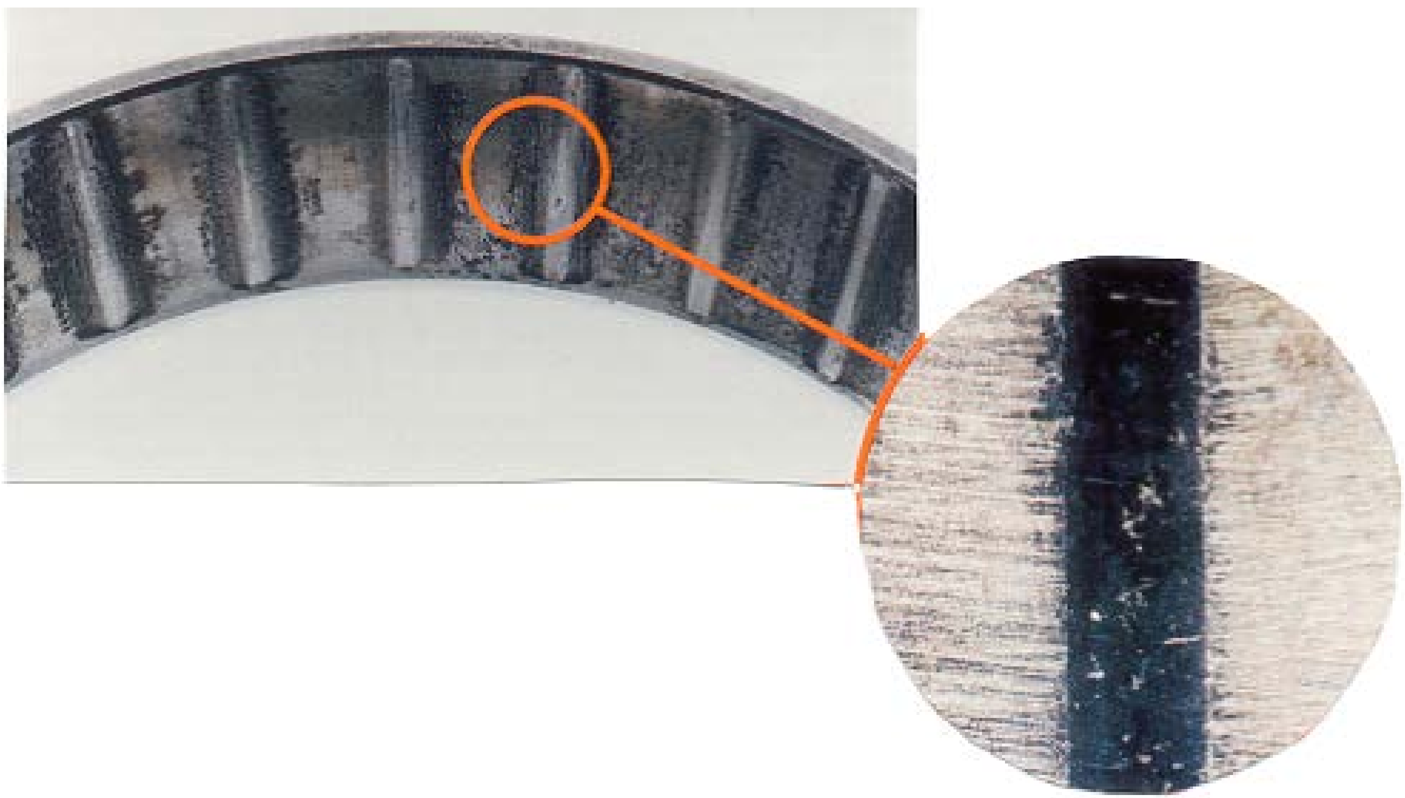
Inadequate Lubrication:
False Brinelling



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Inadequate Lubrication:
Prevention

- Ensure that an appropriate amount of the correct type and grade of lubricant is present
- In environments where lubricant may be washed out, select a sealed bearing
- Ensure that the correct lubricant delivery system is used
- Proper grease pack/distribution
- Ensure flow starts before rotation or operation
- Ensure proper function of lube system: proper flow rates, proper settings and maintenance of metering devices
- Ensure proper temperature in oil sump or inlet

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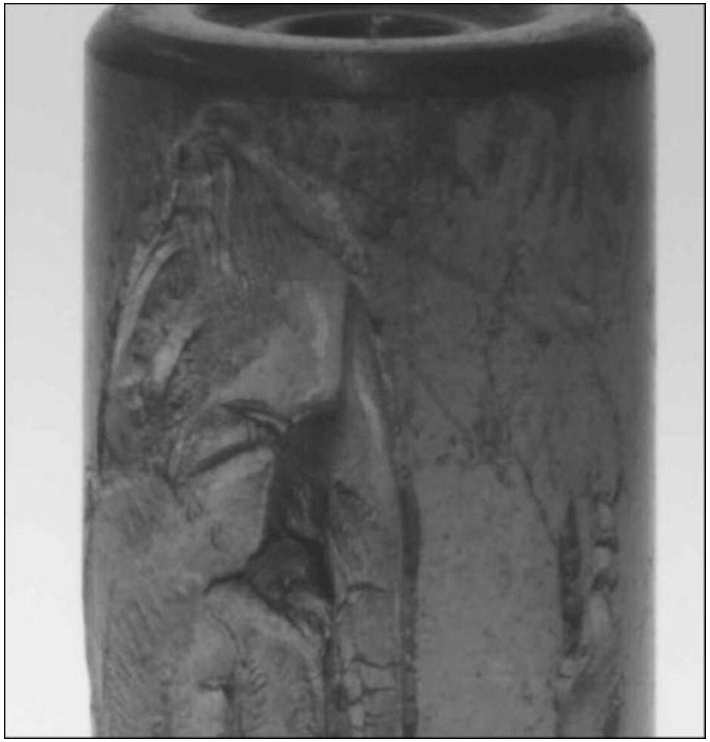
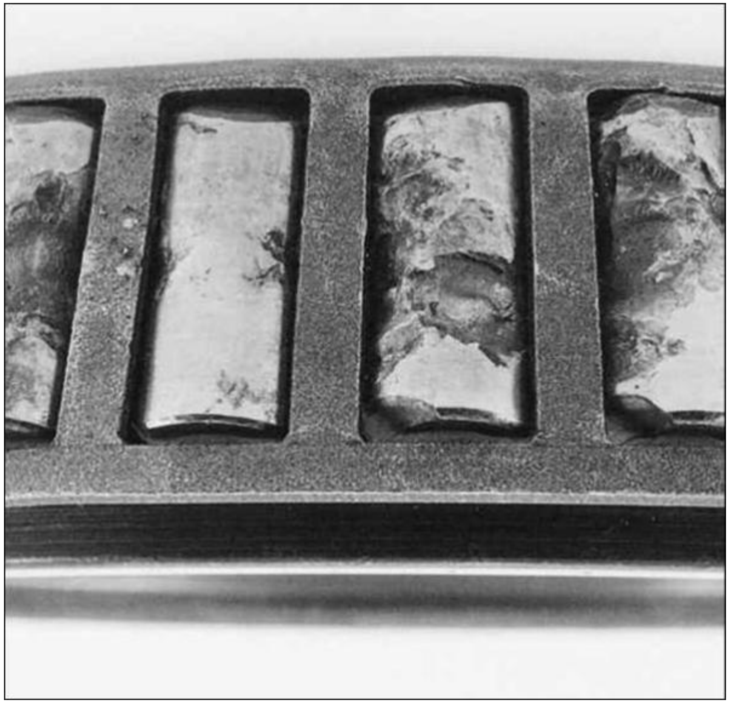
Misuse:

Excessive Preload or Overload



Overloading on a cylindrical roller bearing caused roller surfaces to fracture



Overloading resulted in severe fatigue spalling on the tapered rollers

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Misuse:

Excessive Preload or Overload

Overloading and low speed caused insufficient lubricant film

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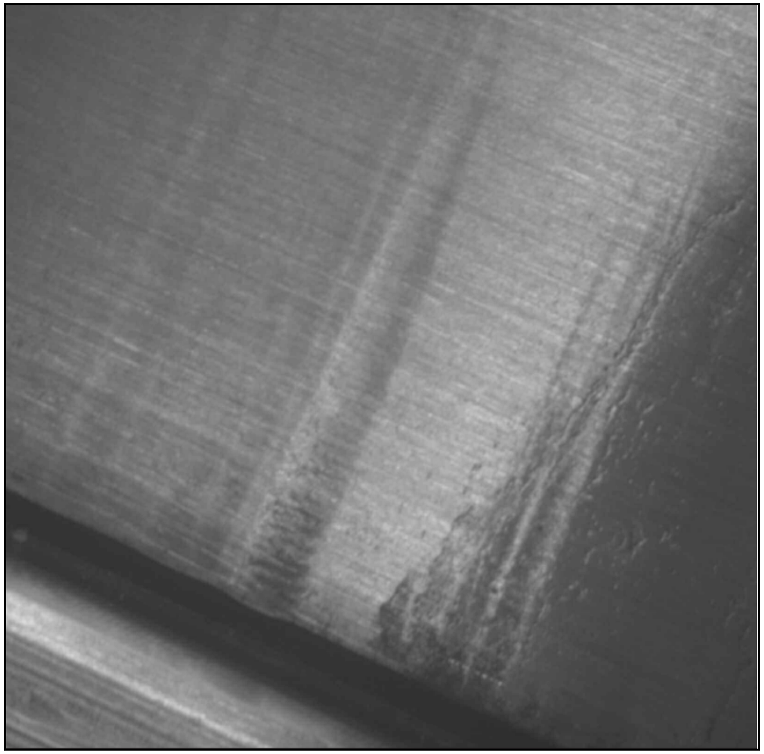
Misuse:
True Brinelling



Spherical roller bearing inner ring showing roller impact damage from shock loading

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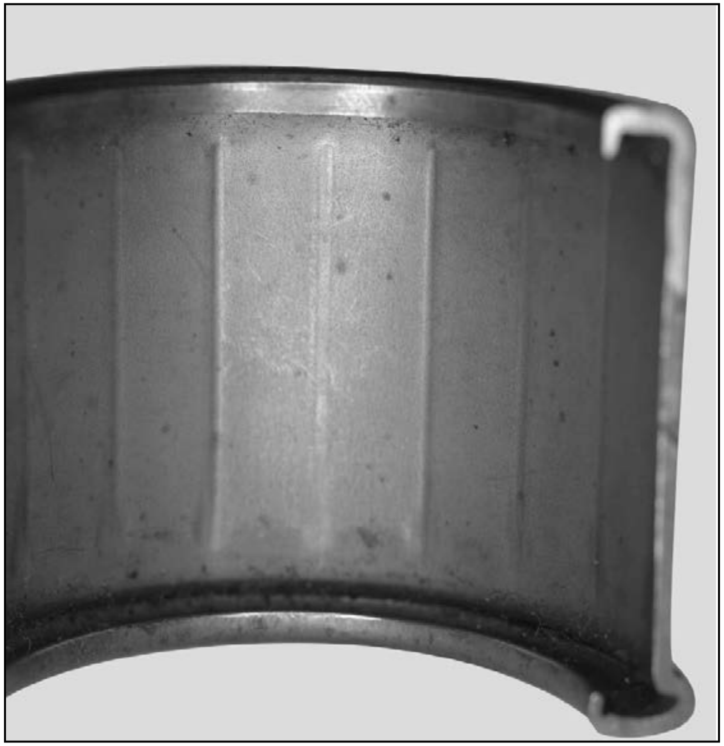
Misuse:
True Brinelling



Needle roller bearing outer ring race with roller-spaced indents from impact during installation

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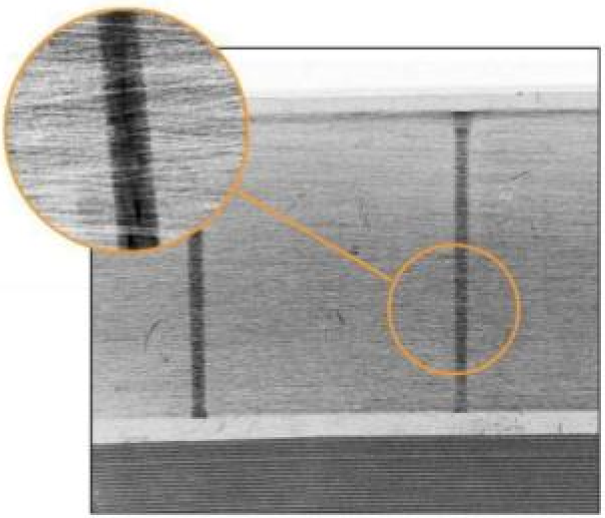
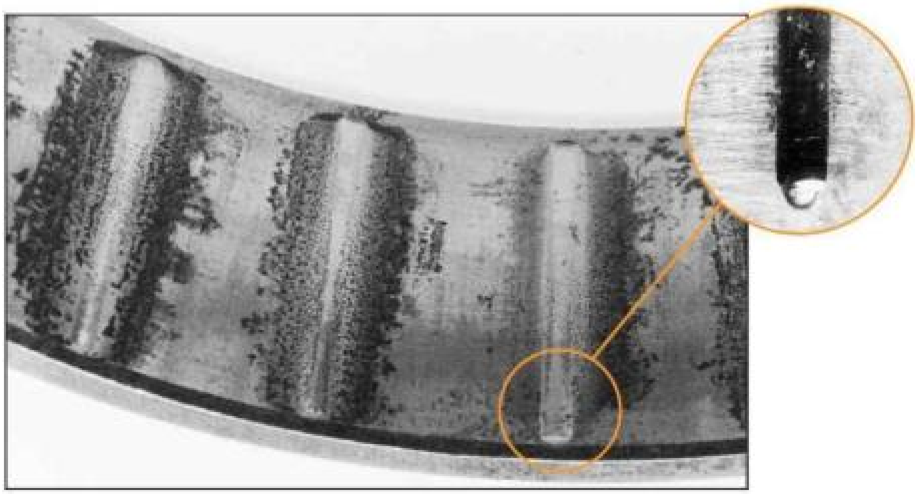
Misuse:

True vs. False Brinelling

- False brinelling wears away the surface texture, while the original surface texture remains in the depression of a true brinell



True Brinelling



False Brinelling

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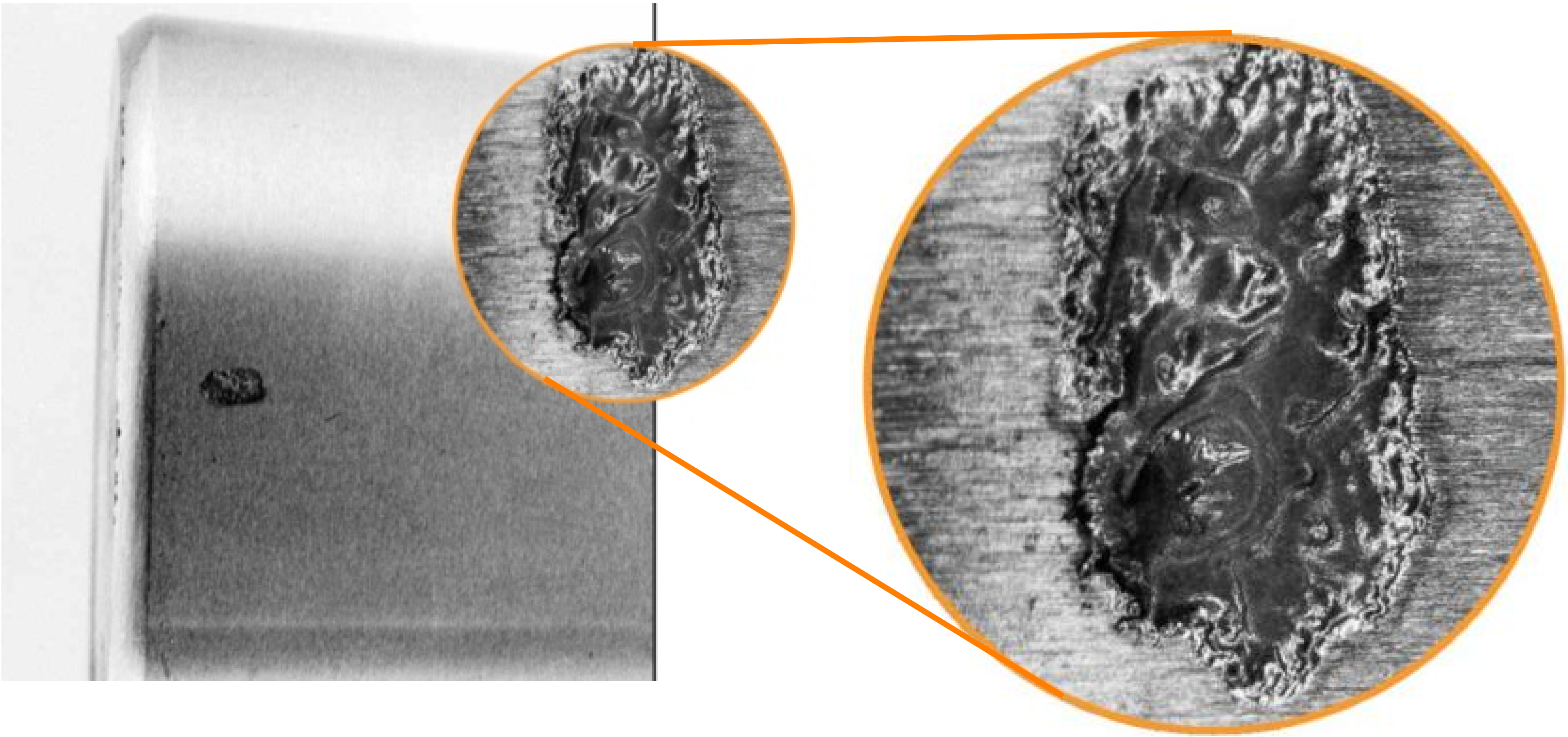
Misuse:
Burns from Electric Current



Pitting / small burns created by arcs from improper electric grounding in stationary bearing

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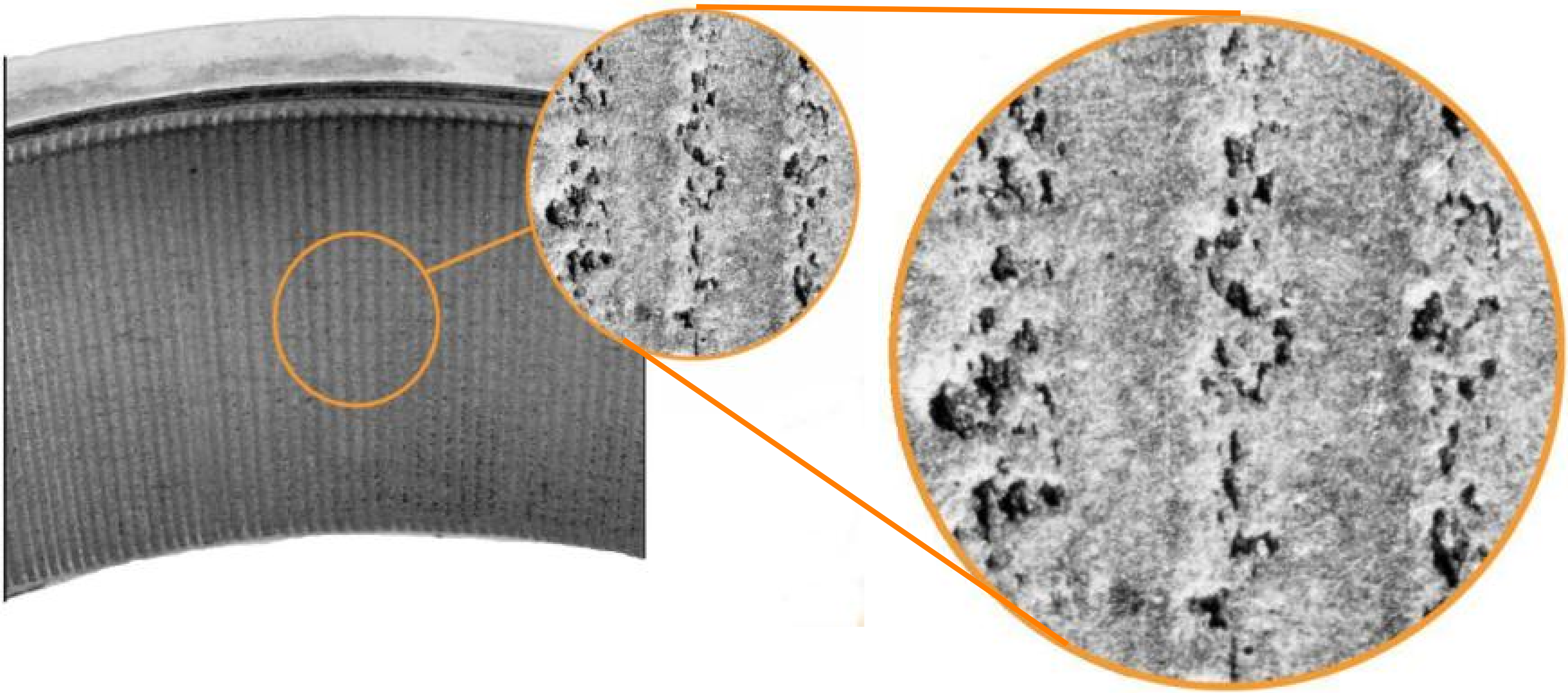
Misuse:
Burns from Electric Current



Fluting (small axial burns) caused by electric current passing through rotating bearing

Misuse:

Burns from Electric Current

Roller with fluting caused by welding performed on machine while bearings were rotating

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Keys To Optimal Bearing Performance

Proper:

- **Selection/Specification**
- **Handling**
- **Installation**
- **Lubrication**
- **Sealing**
- **Cleaning**

Minimize Contamination, Inadequate Lubrication, and Misuse!

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What are White Etch Areas?

- <u>Microstructural Alterations</u>: Phase transformations that occur during service due to high application stresses and/or long service lives.

- The location of nucleation sites for these phase transformations can be found to be either:
  - Random (within a depth interval consistent with high applied stresses – e.g., 0.005”-0.023”)
    - Dark etch regions
    - White etch areas
  - Specific (at lower strength areas or stress risers within the original microstructure or steel)
    - White bands
    - Butterfly

Microstructural Alterations - Terminology

- Dark Etching Areas
  - Dark Tint
  - Dark Line
  - Dark Etching Regions (DER)
  - Dark Needles
  - Dark Etching Bands
- White Bands
  - 80 or 30 Degree Bands
  - White Etch Areas (WEA)
  - White Etching Alterations (WEA)
  - Light Etching Areas
  - Light Etching Region
  - Bright Etching Regions (BER)
  - High/Low Angle Bands
  - Steep/Flat White Band
- Butterfly
  - Stress Butterfly
  - White Etch Areas
- White Etch Cracking
  - White Etch Areas (WEA)
  - Brittle Flaking
  - White Structure Flaking
  - White Band
  - Bright Etched Regions
  - irWEA
    - irregular white etch areas
    - Inner ring white etch areas
- Axial Cracking
  - Radial Cracking

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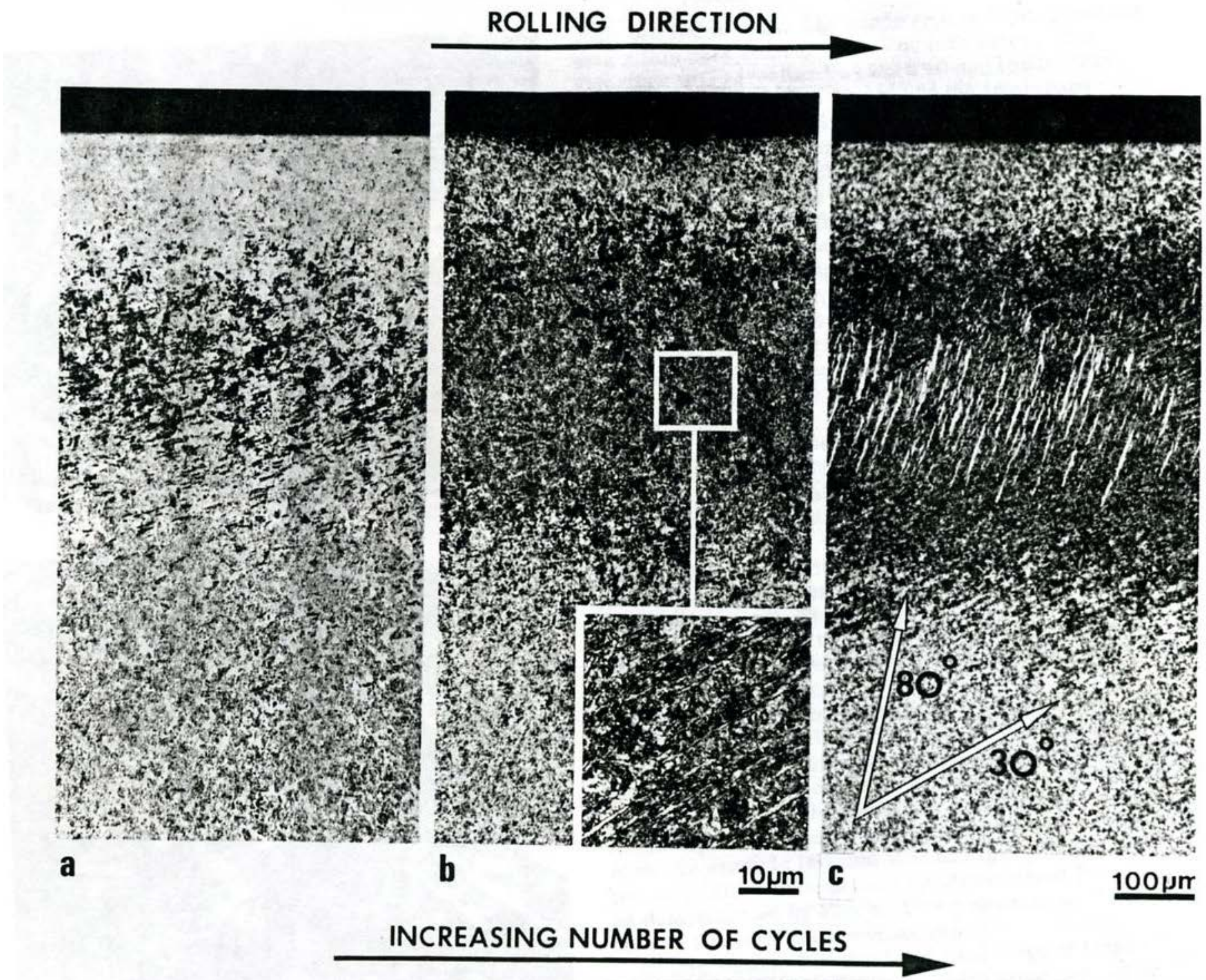
Dark Etching Areas & White Bands



- **Accumulation of subsurface damage with increasing cycles.**

Source: Schwan et al., Metallurgical Transactions A, vol 76, August 1976, page 1100

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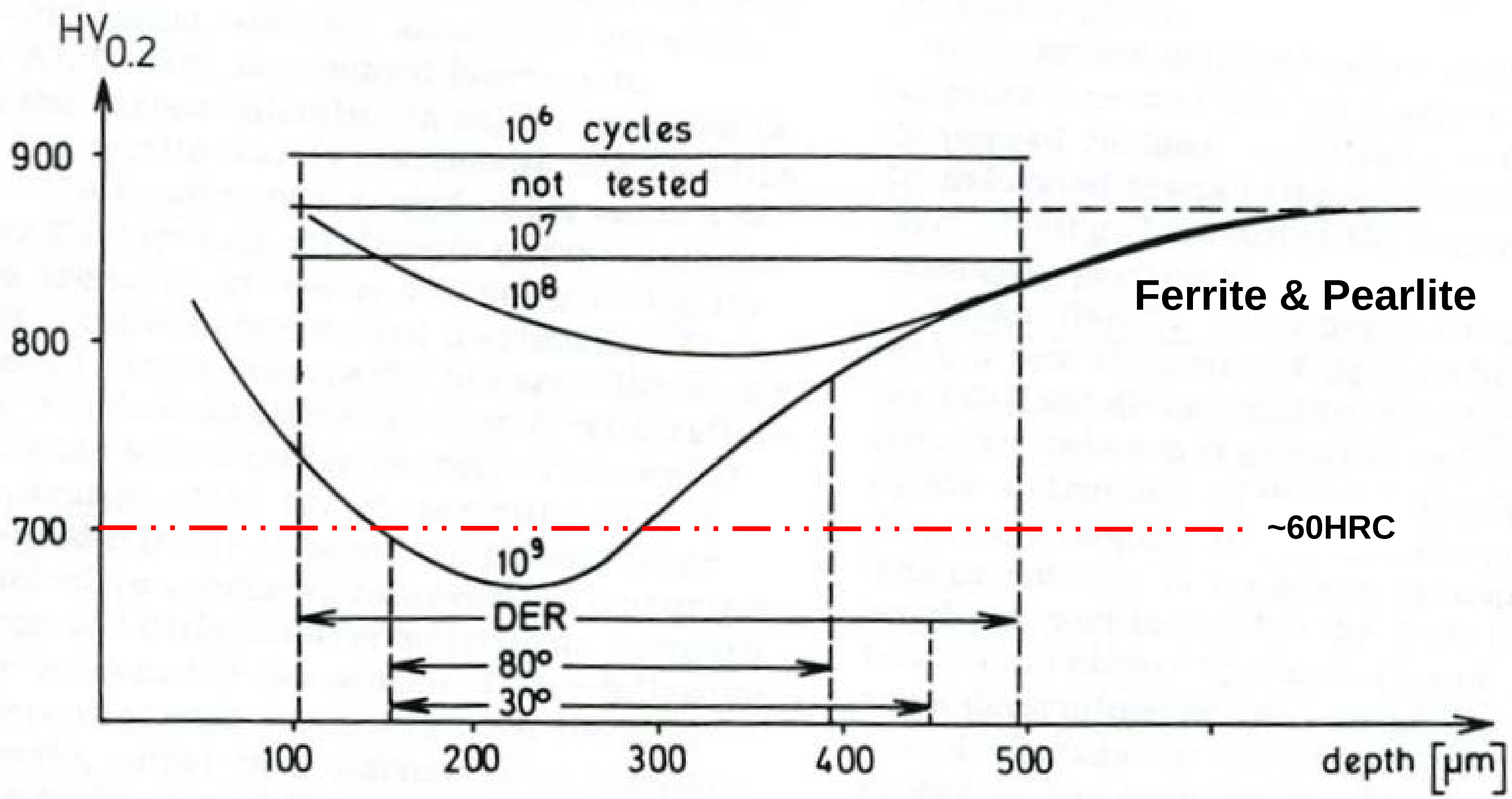
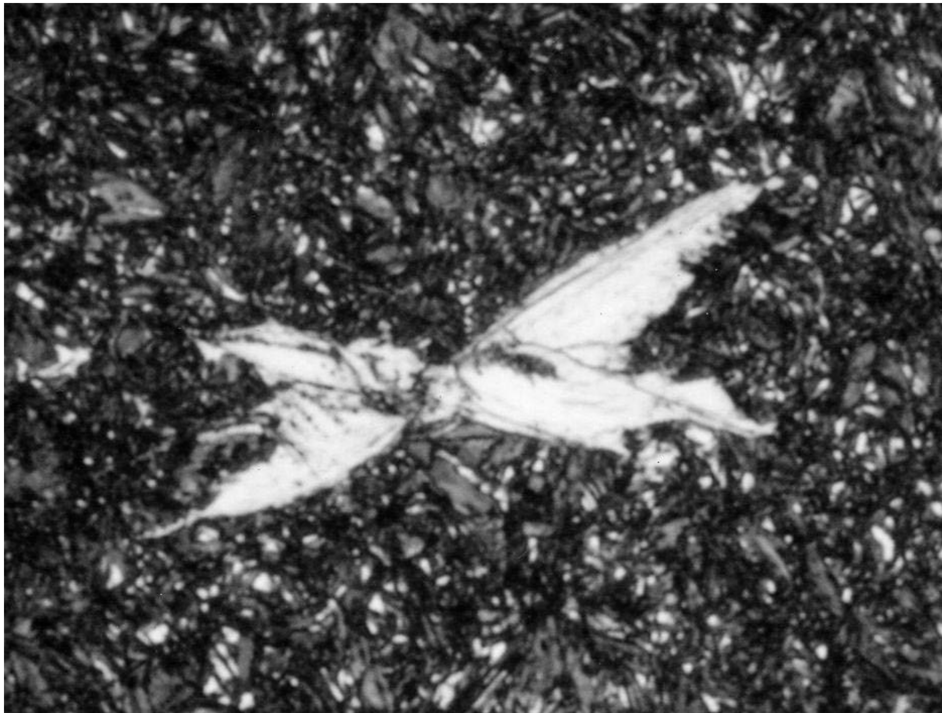
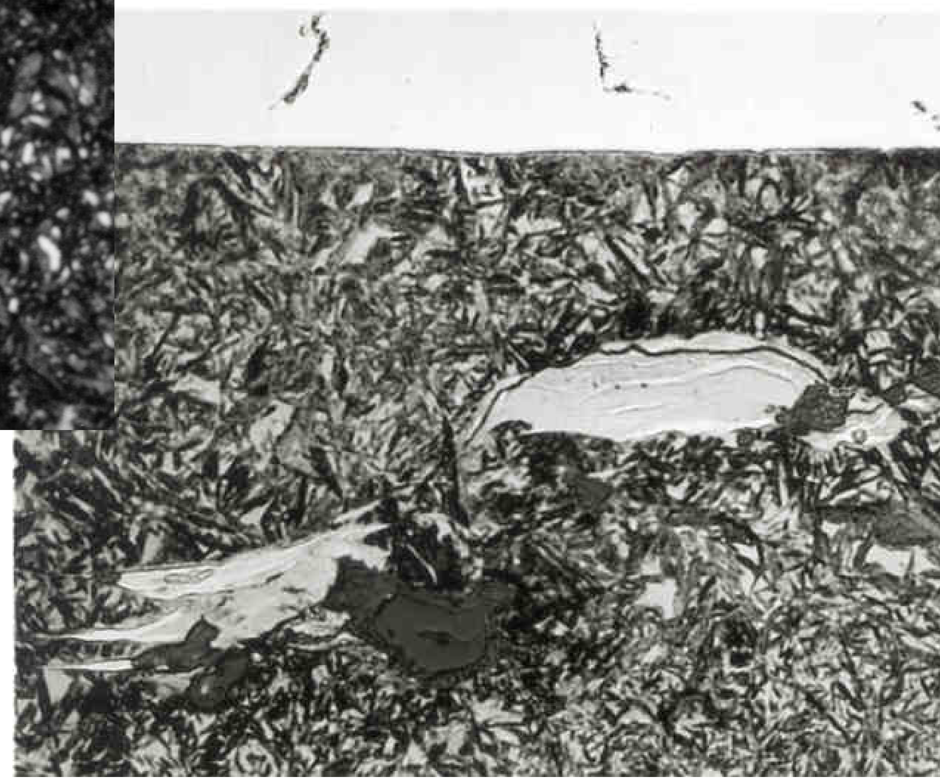
Dark Etching Areas – Hardness Changes



Source: Schwan et al., Metallurgical Transactions A, vol 76, August 1976, page 1101

Butterfly – Morphology & Orientation





Butterfly – Micro Hardness

- SAE 52100
- Knoop Hardness
- Used 25 gram load
- 3% Nital Etch
- Originally 800X
- Nomarski Polarized Lighting

- Matrix = 825 KHN = HRC 64
- Butterfly = 1780 KHN

  >> HRC 70

Source: Torrington Met Lab Archive

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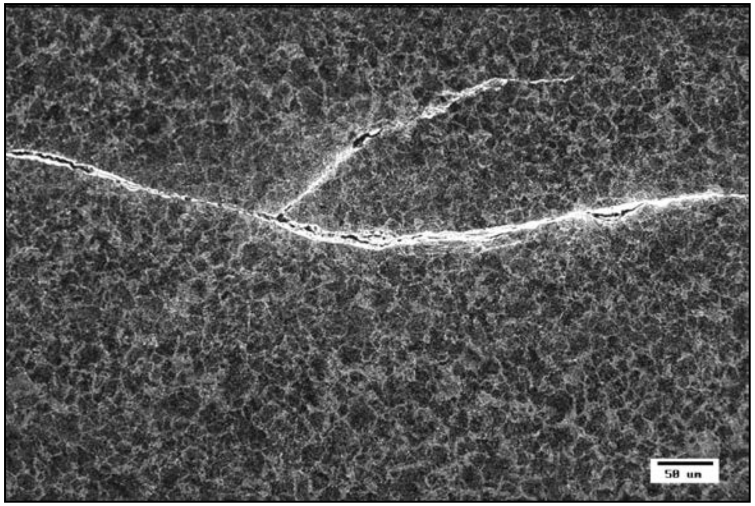
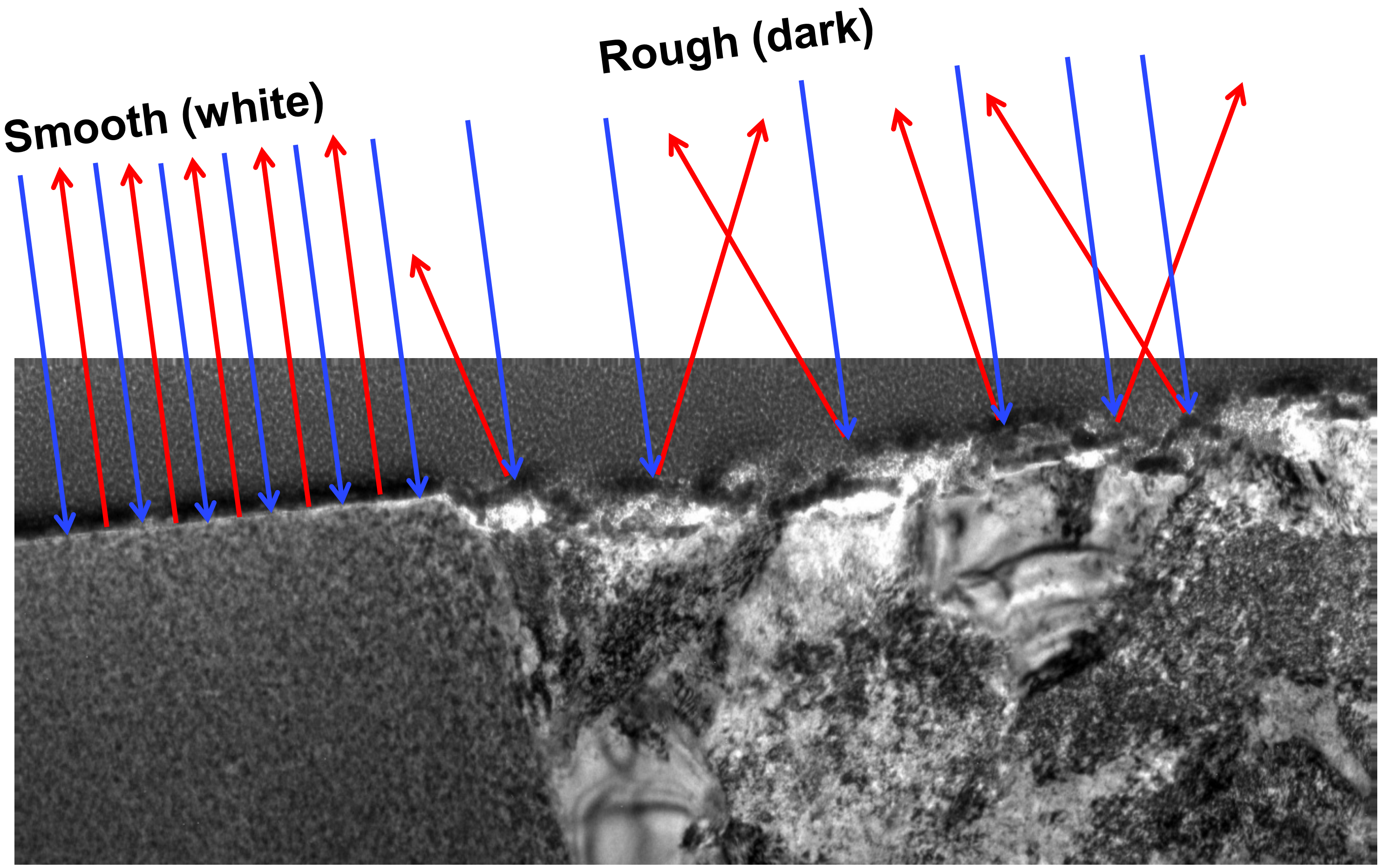
White Etch Cracking



White Etch Areas - TEM

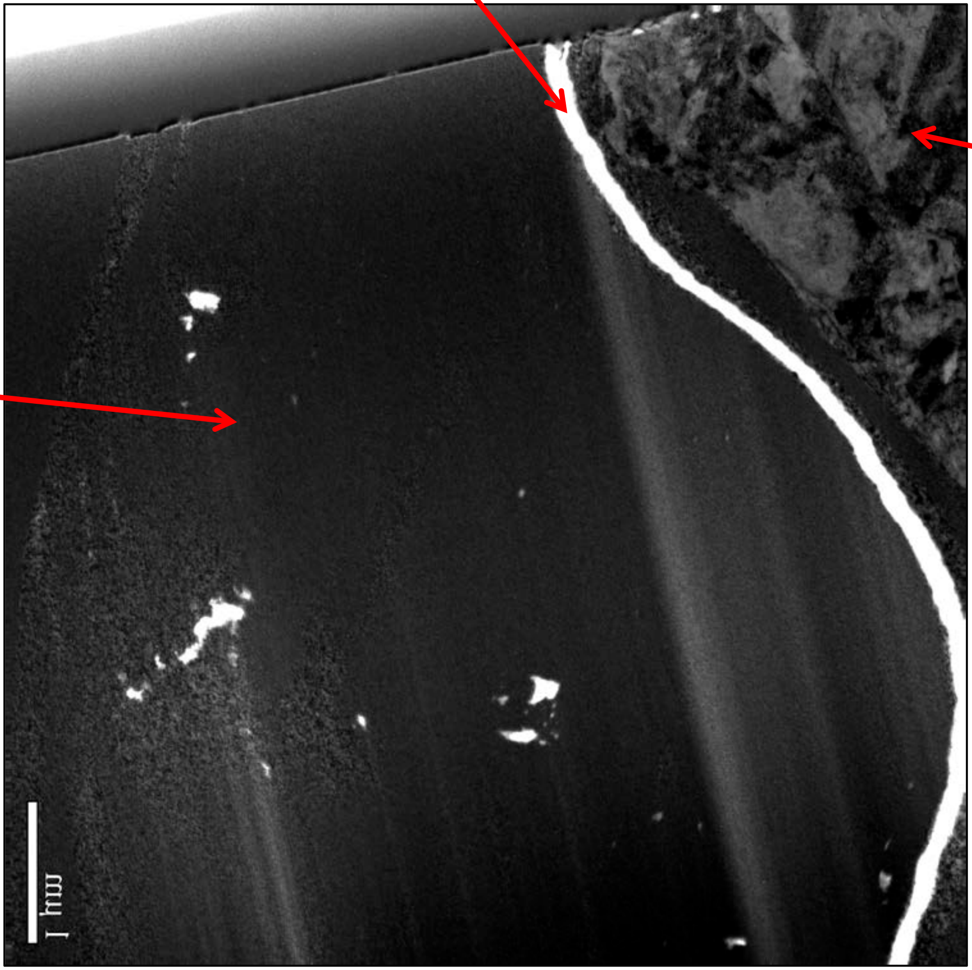


White Etch Areas - TEM

Crack

Original Microstructure

White Etch Area



White Etch Area Take-Aways

- Investigations are underway to better understand WEA network microstructural alterations and their causes.
- Current understanding is that WEA are linked to brittle flaking and possibly axial cracking as well.
- Literature and analogies between WEA networks and stress butterflies/DER-WBs point toward a mechanical root cause, likely involving high stress and slip conditions.

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Summary

- It is usually easy to see bearing damage, but often difficult to determine the cause.
- In many cases the bearing damage may be due to a combination of causes.
- Requires complete investigation of mounting, installation and related parts.
- Smearing was achieved with full-scale CRB in the lab by oscillating the load zone direction, and only Wear-Resistant bearings were able to survive without smearing under those conditions.
- A study of WEA microstructural alterations is underway.

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Questions?

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